

Asteroids as Propulsion Systems of Space Ships

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Currently, rockets are used to change the trajectory of space ships and probes. This method is very expensive and requires a lot of fuel, which limits the feasibility of space stations, interplanetary space ships, and probes. Sometimes space probes use the gravity field of a planet. However, there are only nine planets in the Solar System, all separated by great distances. There are tens of millions of asteroids in outer space. This paper offers a revolutionary method for changing the trajectory of space probes. The method uses the kinetic or rotary energy of asteroids, comet nuclei, meteorites or other space bodies (small planets, natural planetary satellites, space debris, etc.) to increase (to decrease) ship (probe) speed up to 1000 m/sec (or more) and to achieve any new direction in outer space. The flight possibilities of space ships and probes are increased by a factor of millions.

Keywords: Propulsion system, asteroids, comets, trajectory change

1. Introduction

At the present time, rockets are used to carry people and payloads into space, or to deliver bombs over long distances. This method is very expensive and requires a well-developed industry, high technology, expensive fuel, and complex devices [1]. Other than rockets, methods with the potential to accelerate payloads to space speed include space elevators [2], tethers [3,4], and electromagnetic systems [5]. The space elevator is not technically feasible at the present time; it would require substantial costs for development. In particular, the space elevator concept requires extremely strong nanotubes. Tethers are very complex and would require two artificial bodies. Electromagnetic systems are also complex and expensive. The author has previously discussed several other non-rocket launch methods that are potentially low cost, but which require much additional research. These include cable launchers [6 - 10], circle launchers [11], and inflatable towers [12]. This paper examines a new approach, accompanied by a number of technical details related to its feasibility.

There are many small solid objects in the Solar System called asteroids. The vast majority are found in a swarm called the asteroid belt, located between the orbits of Mars and Jupiter at an average distance of 2.1 to 3.3 astronomical units (AU) from the Sun. Scientists know of approximately 6,000 large aster-

oids of diameter 1 kilometer or more, and of millions of small asteroids with diameter 3 meters or more. Ceres, Pallas, and Vesta are the three largest asteroids, with diameters of 1000, 610 and 540 km respectively. Others range all the way down to meteorite size. In 1991 the Galileo probe provided a first close-up view of the asteroid Gaspra, although the Martian moons (already seen close up) may also be asteroids, captured by Mars. There are many small asteroids, meteorites, and comets outside the asteroid belt. For example, scientists know of 1,000 asteroids of diameter larger than one kilometer located near the Earth. Every day one-ton meteorites with mass over 8 kg fall on the Earth. The orbits of large asteroids are well known. The smaller asteroids (from 1 kg) may be located and their trajectory determined by radio and optical devices at distances of hundreds of kilometers.

Radar observations can resolve asteroids by measuring the distribution of echo power in time delay (range) and Doppler frequency. They allow a determination of asteroid trajectory, spin and the creation of an asteroid image.

Most planets, such as Mars, Jupiter, Saturn, Uranus, and Neptune have many small moons that can be used for the proposed space transportation method. There are the asteroids located at the stable Lagrange points of the Earth-Moon system.

These bodies orbit with the same speed as Jupiter, and might be very useful for propelling spacecraft farther out into the solar system. Comets may also be useful for propulsion once a substantial spacecraft speed is obtained. It seems likely that the kinetic and rotational energy of both comets and asteroids will eventually find application in space flight.

Most asteroids consist of carbon-rich minerals, while most meteorites are composed of stony-iron. The present idea [13 - 15] is to utilize the kinetic energy of asteroids, comets, meteorites, and space debris to change the trajectory and speed of space ships (probes). Any space bodies more than 10% of a ship's mass may be used, but here mainly bodies with diameters 2 meters or larger are considered. In this case the mass (20-100 tons) of the space body (asteroid) is some ten times more than the mass of the probe (1 ton) and the probe mass can be disregarded.

2. Connection Method

The method includes the following main steps:

- (a) Searching by a locator or telescope (or finding in catalog) an asteroid and determining its main parameters (location, mass, speed, direction, rotation); selecting the appropriate asteroid; computing the required position of the ship with respect to the asteroid.
- (b) Correcting the ship's trajectory to obtain the required position; converging of the ship with the asteroid.
- (c) Connecting the space apparatus (ship, station, or probe) to a space body (planet, asteroid, moon, satellite, meteorite, etc.) by a net, anchor, and a light strong rope (cable), when the ship has minimum distance to asteroid.
- (d) Obtaining the necessary apparatus position by turning the apparatus around the space body and changing the length of the connection rope.
- (e) Disconnecting the space apparatus from the space body; spooling the cable.

The equipment for changing a probe (spacecraft) trajectory includes:

- (a) A light strong cable (rope).
- (b) A device to measure the trajectory of the spacecraft with respect to the space body.
- (c) A device for spacecraft guidance and control.
- (d) A device for the connection, delivery, control, and disconnection and spooling of the rope.

3. Description of the Utilization

The following describes the general facilities and process for a natural space body (asteroid, comet,

meteorite, or small planet) having a small gravitational force to change the trajectory and speed of a space apparatus.

Figures 1a,b,c show the preparations for using a natural body to change the trajectory of a space apparatus. For example, the natural space body 2, which moves in the same direction as the apparatus (perpendicular to the sketch, Fig. 1a). The ship wants to make a maneuver (change direction or speed) in plane 3 (perpendicular to the sketch), and the position of the apparatus is corrected and positioned in plane 3. It is assumed that the space body has more mass than the apparatus, and that the space body speed has about the same as the speed of the apparatus.

When the apparatus is at the shortest distance R from the space body, the apparatus connects to the space body by net (Fig. 2a, Fig. 3) or by an anchor (Fig. 2b) and rope. The apparatus rotates around the common gravity center on the angle φ with angular speed ω and linear speed ΔV . The cardioids of additional speed and direction of the apparatus are shown on fig. 4 (right side). The maximum additional velocity is $\Delta V = 2V_a$, where V_a is the relative asteroid velocity when the coordinate center is located in the apparatus.

Figure 4b shows the case where the space body moves in the opposite direction of the apparatus with velocity ΔV .

Figure 2a shows how a net can be used to catch a small asteroid or meteorite. The net is positioned on the trajectory of the meteorite or small asteroid, with the net supported in an open position by the inflatable ring and connected to the space apparatus by the rope. The net catches the asteroid and transfers its kinetic energy to the space apparatus. The space apparatus changes its trajectory and speed and then disconnects from the asteroid and spools the cable. If the asteroid is large, the astronaut team can use the asteroid anchor (Figs. 2b, 3).

The astronauts use the launcher (a gun or a rocket engine) to send the anchor (harpoon fork) to the asteroid. The anchor is connected to the rope (spool). The anchor is implanted into the asteroid and connects the space apparatus to the asteroid. The anchor contains the rope spool and a disconnect mechanism (Fig. 3). The space apparatus contains a spool for rope, motor, gear transmission, brake, and controller. The apparatus can include a container for delivering a load to the asteroid and back (Fig. 2b). One possible design of the space anchor is shown in fig. 3. The anchor has a body, a rope, a cumulative charge (shared

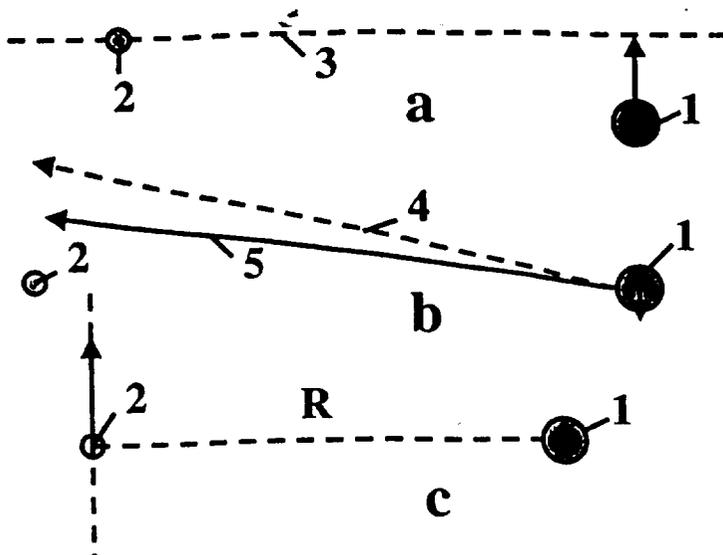


Fig. 1 Preparing for employment of asteroid. Key: 1. space ship, 2. asteroid, 3. plane of maneuver. a) Reaching of the plane of maneuver; b) Correction of flight direction and getting a requested radius; c) Connection to asteroid.

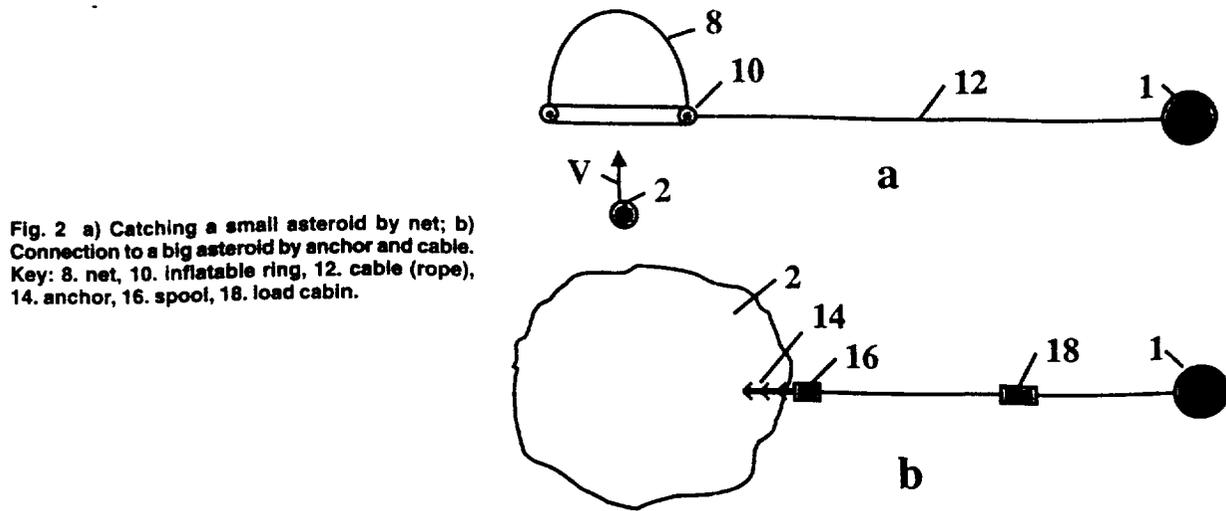


Fig. 2 a) Catching a small asteroid by net; b) Connection to a big asteroid by anchor and cable. Key: 8. net, 10. inflatable ring, 12. cable (rope), 14. anchor, 16. spool, 18. load cabin.

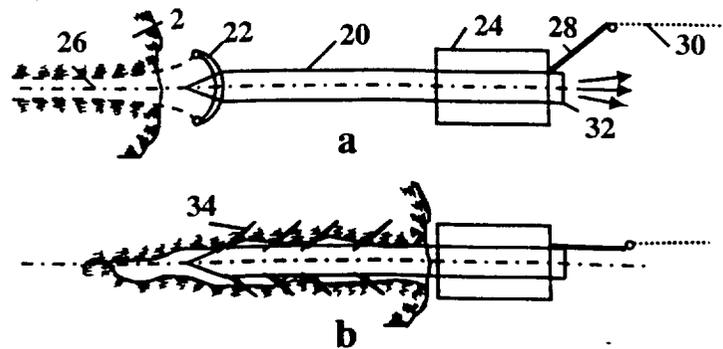


Fig. 3 a) Anchor (harpoon fork). Key: 20. body; 22. cumulative charge (shaped charge), 24. rope spool, 26. canal is made by shaped charge, 28. rope keeper, 30. rope, 32. rocket impulse engine, which implants the anchor to asteroid, 34. anchor catchers. b) Anchor connected to the asteroid.

charge), the rocket impulse (explosive) engine, the rope spool and the rope keeper. When the anchor strikes the asteroid surface the cumulative charge burns a deep hole in the asteroid and the rocket-impulse engine hammers the anchor body into the asteroid. The anchor body pegs the catchers into the walls of the hole and the anchor's strength keeps it attached to the asteroid. When the apparatus is to be disconnected from the asteroid, a signal is given to the disconnect mechanism.

While the method using a net will always work,

the success of the anchor method will depend upon the structure of the asteroid or comet. Some references to the structures and shapes of comets and asteroids are given in the Appendix.

If the asteroid is rotated with angular speed ω (Fig.5), its rotational energy can be used for increasing the velocity and changing the trajectory of the space apparatus. The rotary asteroid spools the rope on its body. The length of the rope is decreased, but the apparatus speed is increased (see momentum theory in physics).

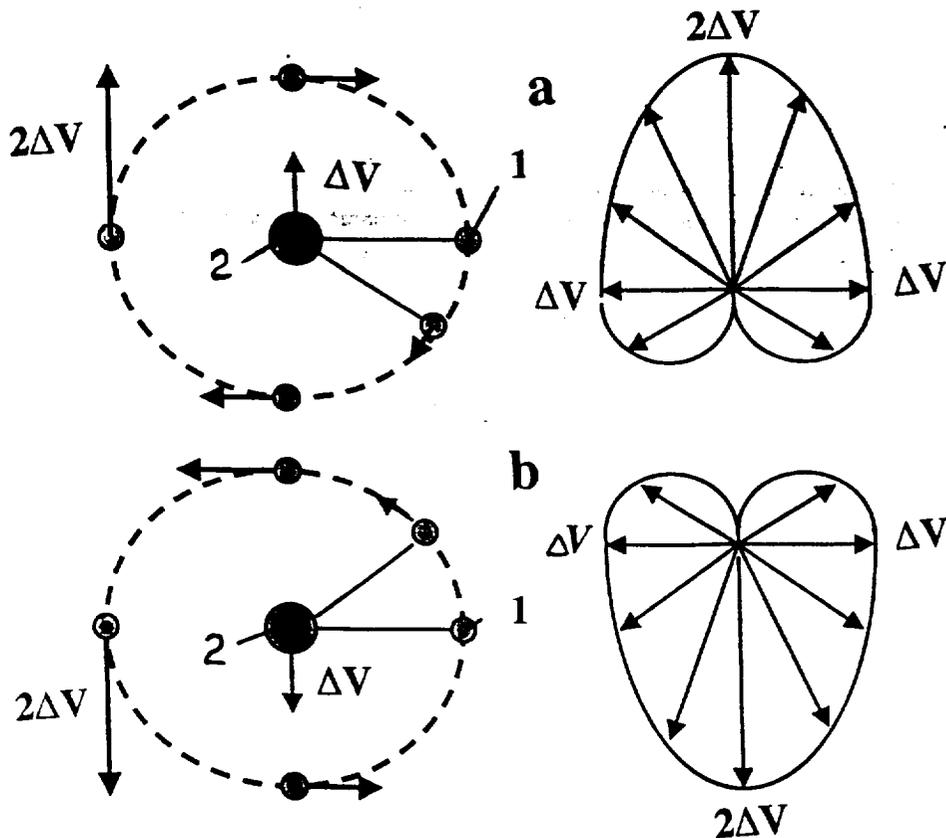


Fig. 4 Using the kinetic energy of asteroid. Change the space ship trajectory (speed and direction) by employment of asteroids. In right side is the cardioid of the additional velocity and its direction. The ship can get this velocity from asteroid. Key: 2. asteroid, 1. space ship, ΔV - difference between velocities of space ship and asteroid. a) Case when the asteroids has same direction as ship; b) case when asteroid has opposite direction ship as.

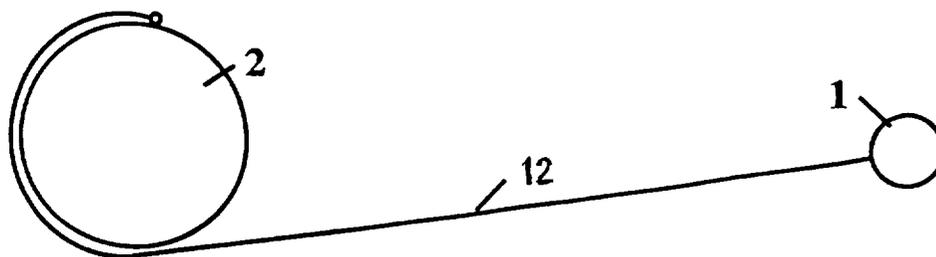


Fig. 5 Using the rotary energy of a rotating asteroid.

The ship can change the length of cable. When the radius is decreased, the linear speed of the apparatus is increased. Conversely, when the radius is increased the apparatus speed is decreased. The apparatus can obtain energy from the asteroid by increasing the length of the rope.

The computations and estimations show the possibility of making this method a reality in a short period of time (see Section 5).

An abandoned space vehicle or large piece of space debris in Earth orbit can also be used for increasing the speed of the new vehicle and for removing the abandoned vehicle or debris from orbit.

4. Theory and Computation

1. The differential equation can be obtained from the equilibrium of a small cable part under centrifugal force. This equation for optimal (equal stress from centrifugal force) cable is

$$da/A = (\omega^2 r \sigma) R dR.$$

Its solution is the cable equal stress

$$a(R) = A/A_0 = \exp(V^2/2k) = \exp(\omega^2 R^2/2k), \quad (1)$$

where a is the relative cross-section area of cable; A is the cross-section area of cable [m^2]; A_0 is the initial (near probe) cross-section area of

cable [m²]; V is the speed of the probe or space ship about the asteroid [m/s]; $k = \alpha\gamma$ is the ratio of cable tensile stress to density [nm/kg]; $K = k/10^7$ is a coefficient (see figs); R is the radius from the common gravity center: asteroid + probe [m]; ω is the angular speed of a probe around the asteroid [rad/sec]; σ is the tensile strength [n/m²]; and γ is the density of cable [kg/m³];

2. Mass W [kg] of the cable is

$$W = A_0\gamma \int_0^R a(r)dr = \frac{F_0}{k} \int_0^R \exp\left(\frac{\omega^2 r^2}{2k}\right) dr, \quad (2)$$

where r = variable [m]; F_0 = force from probe [n]

3. Relative cable mass $W_r = W/W_s$ is

$$W_r = \frac{B}{1+B}, \quad B = \frac{n}{k} \int_0^{V^2/ng} \exp\left[\left(\frac{ng}{V}\right)^2 \frac{r^2}{2k}\right] dr, \quad (3)$$

where the integration interval is $[0, V^2/ng]$, $n=F_0/g$ is the overload, V is the apparatus circular speed about the common center of gravity, W_s = ship (probe) mass, g = Earth gravitation [m/s²], $g = 9.81$ m/s²;

4. Circular velocity of ship around asteroid

$$R = V^2/gn, \quad V = (gnR)^{0.5}. \quad (4)$$

5. Relative mass of cable with constant cross-section area for small speed

$$W_r = W/W_s = \gamma V^2/\sigma g = V^2/kg. \quad (5)$$

6. Determining the additional velocity of the space vehicle obtained from the asteroid.

Taking the coordinate axis along the positive direction of the asteroid velocity vector and writing the momentum and energy laws of the asteroid-apparatus system for this axis gives

$$m_1 V_1 + m_2 V_2 = m_1 u_1 + m_2 u_2 \quad (6)$$

$$0.5m_1 V_1^2 + 0.5m_2 V_2^2 = 0.5m_1 u_1^2 + 0.5m_2 u_2^2 + A, \quad (7)$$

where m_1, V_1 are the mass and asteroid speed before connection to the apparatus; m_2, V_2 are the mass and apparatus speed before connection to the asteroid; u_1 is the asteroid speed after disconnection from the apparatus; u_2 is the apparatus

speed after disconnection from the asteroid; A is the energy (work) applied by the apparatus to change the length of the connection cable.

Locate the axis origin in the apparatus ($V_2=0$) and apply the note $V = V_1$ = asteroid speed about the apparatus; $u = u_2$ = additional apparatus speed; $m = m_2/m_1$ = the relative apparatus mass.

Substitute u_1 from (6) into (7), to obtain the quadratic equation in variable u

$$(m+1)u^2 - 2Vu + 2A/m_1 m = 0. \quad (8)$$

The solution of this equation is

$$u = \{V \pm [V^2 + 2A(m+1)/m m_1]^{0.5}\}/(m+1). \quad (9)$$

Note that if $A = 0$ (apparatus does not change the length of connection cable) and the asteroid mass is large ($m \approx 0$), then the maximum of apparatus additional speed is $u = 2V$ in the asteroid speed direction and $V = 0$ in the opposite direction. If $A \neq 0$, the maximum work (energy), which the apparatus can receive from the asteroid by increasing connection cable is bounded by

$$A \leq m m_1 V^2/2(m+1). \quad (10)$$

If the apparatus expends internal energy (decreases the length of the connection cable), the additional apparatus speed is limited ONLY by the admissible cable strength and the apparatus overload. The apparatus DOES NOT SPEND apparatus mass for increasing its speed.

If the apparatus is disconnected in a direction with angle φ to the asteroid speed direction, the additional apparatus speed is

$$\Delta V = V(1 + \cos \varphi). \quad (11)$$

where V = initial speed of the asteroid about the space ship [m/s] (coordinate center is located in the space apparatus); ΔV = ship additional speed received from the asteroid [m/s]; φ = angle between the old velocity vector of the asteroid and the new velocity vector of the apparatus.

The additional apparatus kinetic energy is

$$E_k = 0.5m_2(\Delta V)^2. \quad (12)$$

7. The known formulas below may be useful:

$$V = \omega R; \quad V_2 R_2 = V_1 R_1; \quad V_1 = R_2 (g/R)^{0.5}; \\ V_2 = V_1 (2)^{0.5}; \quad R_2 = (g R_1^2 / \omega^2)^{1/3}. \quad (13)$$

where V_1 = circular speed around the Earth, V_2 = escape speed, R_1 = Earth radius, R_2 = radius of geosynchronous Earth orbit.

5. Project

The capability to change the trajectory and speed of a space vehicle by an asteroid is shown in fig. 4. The space ship could obtain a maximum additional speed equal to two times the speed difference between the space vehicle and the asteroid (speed of asteroid about space ship). If the length of the connection cable is changed, the speed of the space ship could change by more than double the speed difference. If the asteroid is rotating, the space ship can also obtain an additional speed increase from the rotation. The additional speed from one asteroid is also limited (for a manned ship) by the mass of the cable. For an additional speed of 1,000 m/sec and $K = 0.2$, the mass of cable would equal 5% of the mass of the space apparatus. For an additional speed of 2,000 m/sec, the mass of cable would equal 23% of the mass of the space apparatus. For travel to an asteroid, a connection device may be mounted to the transport cable. The cable may be used multiple times.

The results of computation for different cases are shown in figs. 6-11. If the change of ship speed is less than 1,000 m/sec, the conventional widely produced fiber (admissible $K = 0.1$) can be used. The cable mass is about 8% of the ship mass. After disconnection the cable will be spooled and can be used again. The reader can make the estimation for other cases. Radio or optical devices can locate the asteroids at thousands of kilometers. Their speed, direction of flight and mass can be computed. The ship (probe) can make small corrections to its own trajectory to get the required position about the asteroid. Asteroids with diameter over one kilometer are in astronomical catalogs and their trajectories are well known. One thousand of them are located near the Earth. For these, we can compute in advance the intercept parameters. At the present time, a long-range space apparatus uses the gravity of a planet to change its trajectory. However, the Solar system has only nine planets, and they are located very far from one another. The employment of asteroids increases this possibility a million times over.

6. Discussion

6.1 Estimation of Probability of Meeting a Small Asteroid

It is known that every day about one ton of meteor-

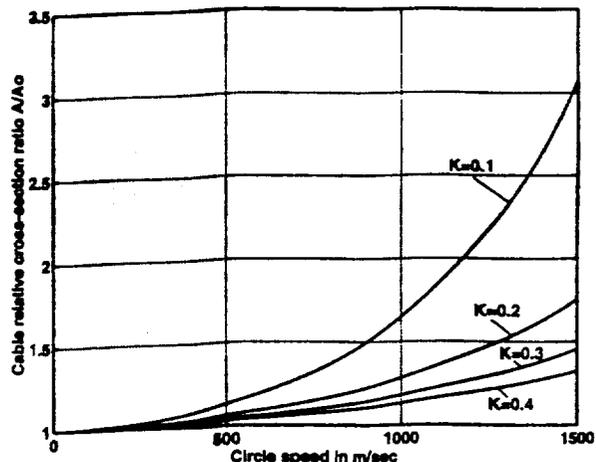


Fig. 6 Asteroid cable relative ratio via circle speed and coefficient $K = 0.1 - 0.4$.

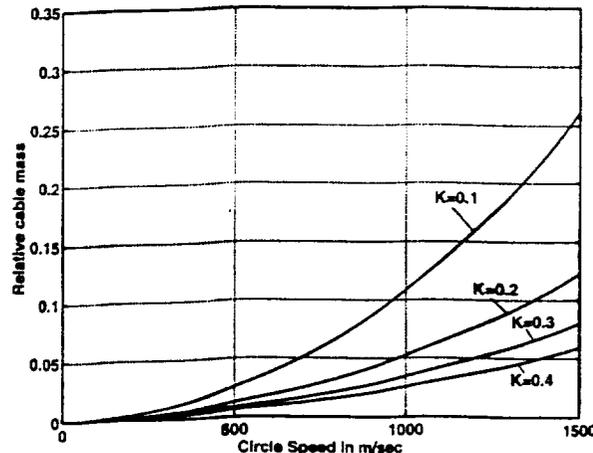


Fig. 7 Relative cable asteroid mass via circle speed in m/sec and coefficient $K = 0.1 - 0.4$

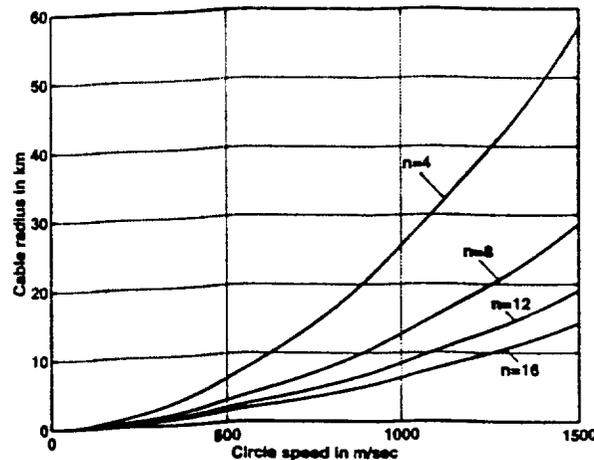


Fig. 8 Cable radius in km via circle speed in m/sec and overload $n = 4 - 16$.

ites having a mass greater than 8 kg fall into the Earth's atmosphere. The Earth's surface area is about 512 million km^2 . If the average mass of a meteorite is 10 kg, then Earth encounters 100 meteorites per day, or one meteorite per day per every 5 million km^2 . If a space probe has a mass about 100 kg, then a 10 kg meteorite has enough mass to

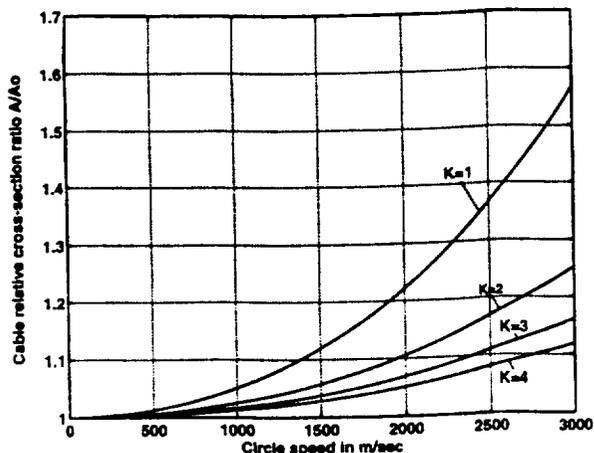


Fig. 9 Asteroid cable relative ratio via a circle speed and coefficient $K = 1 - 4$.

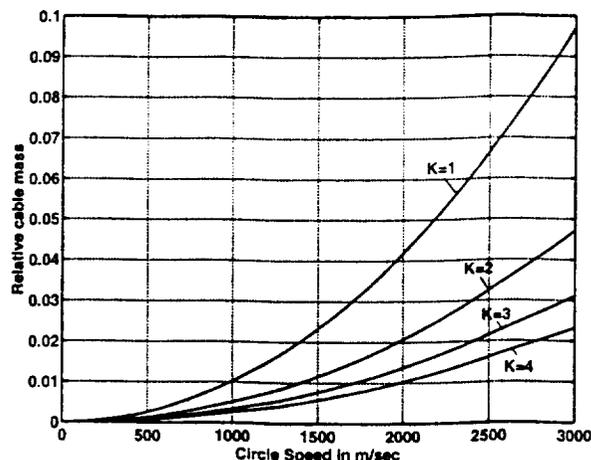


Fig. 10 Relative cable asteroid mass via circle speed in m/sec and coefficient $K = 1 - 4$.

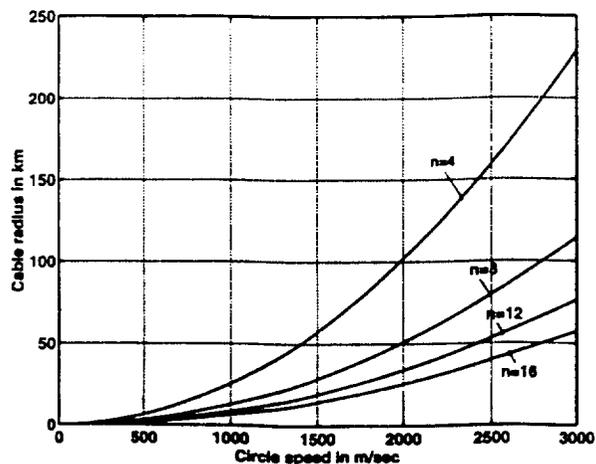


Fig. 11 Cable radius in km via circle speed in m/sec and overload $n = 4 - 16$.

change the direction and speed of that probe. Ground locators can detect a one kg space mass at a distance up to thousands km. If the space ship can detect similar size objects at a range of one thousand km, then it can see a space body with an area of one million km² or about one meteorite in every 5 days. If one meteorite in ten is suitable for

employment, then every 50 days the space apparatus will meet an eligible meteorite near the Earth. The likelihood is ten times greater in the asteroid belt between Mars and Jupiter. For 6,000 big asteroids, we can compute the intercept parameters now. This number is expected to increase as register more small asteroids are registered.

There are about 8,000 fragments of old rockets and space equipment near Earth. The trajectories of those are known. They also can be used for accelerating the space apparatus. In this case there is a double benefit: to accelerate the current space apparatus and remove space garbage from the Earth's atmosphere (or outer space). This space garbage is dangerous for current ships and this problem will increase every year.

Note that the kinetic energy of space bodies may be used if the space body has a DIFFERENT speed or direction. It is difficult to use a tether system (for example, the last stage of a rocket and Shuttle ship) because they have the same speed and direction.

6.2 Concerning the Cable

If the required change of speed is less than 1,000 m/sec, then cable from current artificial fibers can be used. Twenty years ago, the mass of the required cable would not allow this proposal to be possible for an additional speed of more 2,000 m/sec from one asteroid. However, today's industry widely produces artificial fibers with tensile strength 3-5 times more than steel and density 4-5 times less than steel. There are experimental fibers with tensile strength 30-60 times more than steel and density 2 to 4 times less than steel. For example, Galasso [16] quotes data for a fiber C_D with tensile strength $H = 8000 \text{ kg/mm}^2$ and density (specific gravity) $D = 3.5 \text{ g/cm}^3$. If an allowed strength of 7000 kg/mm^2 ($H = 7 \times 10^{10} \text{ n/m}^2$, $D = 3500 \text{ kg/m}^3$) is taken, then the ratio $D/H = 0.05 \times 10^{-6}$ or $H/D = 20 \times 10^6$ ($K = 2$). Although (1976) the graphite fibers are strong ($H/D = 10 \times 10^6$), they are at best still ten times weaker than theory predicts.

Steel fiber has a tensile strength of 5,000 MPA (500 kg/mm²); the theoretical value is 22,000 MPA (1987). The polyethylene fiber has a tensile strength of 20,000 MPA and the theoretical value is 35,000 MPA (1987).

The mechanical behavior of nanotubes is also exciting because nanotubes are seen as the ultimate carbon fiber, which can be used as reinforcement in advanced composite technology. Early theoretical

work and recent experiments on individual nanotubes (mostly MWNT's) have confirmed that nanotubes are one of the stiffest materials ever made. Whereas carbon-carbon covalent bonds are one of the strongest in nature, a structure based on a perfect arrangement of these bonds oriented along the axis of nanotubes would produce an exceedingly strong material. Traditional carbon fibers show high strength and stiffness, but fall far short of the theoretical in-plane strength of graphite layers (an order of magnitude lower). Nanotubes come close to being the best fiber that can be made from graphite structure.

For example, whiskers made from carbon nanotubes (CNT) have a tensile strength of 200 giga Pascals and a Young's modulus of over 1 tera Pascals (1999). The theory predicts 1 tera Pascals and Young modulus of 1-5 tera Pascals. The hollow structure of nanotubes makes them very light (a specific density varies from 0.8 g/cc for SWNT's up to 1.8 g/cc for MWNT's, compared to 2.26 g/cc for graphite or 7.8 g/cc for steel).

Specific strength (strength/density) is important in the design of our Employment Asteroid System, Space Transportation System and Space Elevator [6 - 12, 14, 15, 17,18]; nanotubes have a specific strength at least 2 orders of magnitude greater than steel. Traditional carbon fibers have a specific strength 40 times that of steel. Where nanotubes are made of graphitic carbon, they have good resistance to chemical attack and have high thermal stability. Oxidation studies have shown that the onset of oxidation shifts by about 100 °C to higher temperatures in nanotubes compared to high modulus graphite fibers. In vacuum or reducing atmospheres, nanotube structures will be stable to any practical service temperature. Nanotubes also have excellent conductivity, similar to copper.

The price of whiskers of SiC produced by the Carborundun Company with $\sigma = 20,690$ MPa, and $\gamma = 3.22$ g/cc was 440 \$/kg in 1989. The medical,

environmental, space, aviation, machine-building, and computer industries all need cheap nanotubes. Some American companies plan to produce nanotubes in 2-3 years. In the following section, a brief overview of the annual research information (2000) regarding the proposed experimental test fibers is provided.

7. Modern Cable Data

Consider the following experimental and industrial fibers, whiskers, and nanotubes:

1. Experimental nanotubes CNT (carbon nanotubes) have a tensile strength of 200 giga Pascals (20,000 kg/mm²), with a Young's modulus of over 1 tera Pascal, and a specific density $\gamma = 1800$ kg/m³ (1.8 g/cc) (Year 2000).

For a safety factor $n = 2.4$, $\sigma = 8,300$ kg/mm² = 8.3×10^{10} n/m², $\gamma = 1800$ kg/m³, $(\sigma/\gamma) = 46 \times 10^6$, $K = 4.6$. The SWNT nanotubes have a density of 0.8 g/cc; MWNT nanotubes have a density of 1.8 g/cc. About 300 kg of nanotubes will be produced in the USA in 2002 [22]. The whiskers C_D have $\sigma = 8000$ kg/mm², $\gamma = 3500$ kg/m³ (1989) [16,p.158], $K = 2.28$.

3. Industrial fibers have $\sigma = 500 - 600$ kg/mm², $\gamma = 1800$ kg/m³, $\sigma/\gamma = 2.78 \times 10^6$, $K = 0.278 - 0.333$.

Properties for some other experimental whiskers and industrial fibers are shown in Table 1.

8. Conclusion

The availability of both current and new materials make the suggested propulsion system and projects highly realistic for a long trip to outer space with minimum expenditure of energy. The same idea was used in the research and calculation of other revolutionary innovations such as: launches to space without rockets (not space elevator, not gun); cheap delivery of loads from one continent to another across space; cheap delivery of fuel gas over long

TABLE 1: Properties of Some Relevant Materials.

Material	Tensile strength	Density	Fibers	Tensile strength	Density
Whiskers	kg/mm ²	g/cc		kg/mm ²	g/cc
AlB ₁₂	2650	2.6	OC-8805	620	1.95
B	2500	2.3	TM9	600	1.79
B ₄ C	2800	2.5	Thorael	565	1.81
TiB ₂	3370	4.5	Allien 1	580	1.56
Graphite	197	1.67	Allien 2	300	0.97
SiC	1380-4140	3.22			

Reference [16, 19, 20, 21].

distances without steel tubes or damage to environment; low cost delivery of large load flows across sea streams and mountains without bridges or underwater tunnels (Gibraltar, English Channel, Bering Straits (USA-Russia), Russia-Sakhalin-Japan, etc.); new economical Transportation Systems; getting inexpensive energy from air streams at high altitudes; etc. Some of them are presented in [6 - 12, 15, 17, 18].

The author has developed novel ideas and related computations for the above-mentioned prob-

lems. Even though these projects may seem impossible using the current technology, the author is prepared to discuss project details with serious organizations with similar research and development goals.

9. Acknowledgement

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